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Clinical effectiveness of robotic versus laparoscopic and open surgery: an overview of systematic reviews

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ABSTRACT

Objective To undertake a review of systematic reviews on the clinical outcomes of robotic-assisted surgery across a mix of intracavity procedures, using evidence mapping to inform the decision makers on the best utilisation of robotic-assisted surgery.

Eligibility criteria We included systematic reviews with randomised controlled trials and non-randomised controlled trials describing any clinical outcomes.

Data sources Ovid Medline, Embase and Cochrane Library from 2017 to 2023.

Data extraction and synthesis We first presented the number of systematic reviews distributed in different specialties. We then mapped the body of evidence across selected procedures and synthesised major findings of clinical outcomes. We used a measurement tool to assess systematic reviews to evaluate the quality of systematic reviews. The overlap of primary studies was managed by the corrected covered area method.

Results Our search identified 165 systematic reviews published addressing clinical evidence of robotic-assisted surgery. We found that for all outcomes except operative time, the evidence was largely positive or neutral for robotic-assisted surgery versus both open and laparoscopic alternatives. Evidence was more positive versus open. The evidence for the operative time was mostly negative. We found that most systematic reviews were of low quality due to a failure to deal with the inherent bias in observational evidence.

Conclusion Robotic surgery has a strong clinical effectiveness evidence base to support the expanded use of robotic-assisted surgery in six common intracavity procedures, which may provide an opportunity to increase the proportion of minimally invasive surgeries. Given the high incremental cost of robotic-assisted surgery and longer operative time, future economic studies are required to determine the optimal use of robotic-assisted surgery capacity.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ This study is the first overview of systematic reviews to summarise the full body of evidence of clinical outcomes across a range of procedures in several specialties.
⇒ This overview is likely to be generalisable to all countries and procedures as the included systematic reviews in our studies are from a broad range of settings.
⇒ This study uses a combination of an overview approach and a novel evidence-mapping method to provide readers with both the evidence landscape and in-depth information in a visual format.
⇒ Our detailed review, which covered the years 2017–2023 and included studies published in English, focused on a limited number of procedures.

INTRODUCTION

Robot-assisted surgery (RAS) is a form of minimally invasive surgery (MIS) involving a telemanipulation system comprising a surgeon console, computerised control system and patient-side cart with robotic arms. RAS offers improved dexterity, better ergonomics and enhanced fixed operator-controlled visualisation and retraction, thus improving the capabilities of surgeons during complex surgery.[1] The use of RAS has grown rapidly and is performed worldwide, with 12 million procedures performed using the da Vinci system since inception.[2] The most widespread growth of RAS is in urology, with over 90% of prostatectomies in the USA and over 85% in the UK over the past decade. Globally, other specialties like upper and lower gastrointestinal (GI) surgery, hepatopancreaticobiliary (HPB) surgery and gynaecology have also experienced increased RAS volume, though it currently constitutes a small proportion of total procedural volume.[3]

The idea, development, exploration, assessment and long-term study (IDEAL) framework conceptualises the evidence shaping process for surgical innovation.[4] Research has shown that innovators often omit stages in evidence generation with a lack of randomised controlled studies and an extensive reliance on observational studies and implementation into practice.[4] This is partly because there are many difficulties in conducting randomised studies for surgical innovation, which include preferences from patients and surgeons, unwillingness to accept randomisation, difficulties in concealing allocation, inadequate subjects for effect size, learning curve and incremental innovation.[5] Moreover, evidence of clinical effectiveness can be lacking in surgical innovation because regulatory pathways do not incentivise evidence generation, and a limited number of clinical studies are required for approval.[6 7] Hospitals may invest in equipment RAS device prior to determining which procedures it will be used for, with some acquisitions motivated by the desire to enhance hospital reputation or attract top-tier surgeons and trainees.[8 9] Accordingly, an important consideration for hospitals is determining how best to optimise the utilisation of these technologies once acquired, in order to justify their initial investment and realise their full potential in enhancing patient outcomes and improving overall healthcare delivery.

The first step for decision makers is to ensure that patient safety is prioritised and that the selected procedures are at least equally effective compared with traditional methods. A previous overview review found limited evidence, with only 18 randomised controlled trials (RCTs) across various surgical procedures comparing robotic surgery to conventional approaches, highlighting challenges in drawing overall conclusions on the sustained effectiveness of robotic surgery.[10] Second, the cost-effectiveness of RAS would be assessed across the selected mix of procedures to justify initial investment and ongoing expansion, ensuring value and optimal use of resources. Given that RAS is a 'platform' technology (in that it can be used across numerous indications),[11] it is important to fill its capacity in the most cost-efficient manner, which requires decision makers to prioritise among candidate procedures. Therefore, to facilitate this decision-making process, our aim in this overview review is to present evidence comparing outcomes across different intracavity procedures in four clinical specialties (colorectal, gynaecology, upper GI and HPB, where RAS versus laparoscopic or open surgery is still in equipoise.

METHODS

Given the breadth of our scope, we adopted the overview of reviews approach as described by Cochrane methods[12] and followed Preferred Reporting Items for Overviews of Reviews (PRIOR) on reporting.[13]

Search methods for identification of reviews

Our search strategy was based on a developed strategy by the Health Improvement Scotland to identify systematic reviews comparing RAS to conventional surgical approaches in humans, and it has been verified by the University of Glasgow Information Scientist. The databases Ovid Medline, Embase and the Cochrane Library are limited to the most recent years (from April 2017 to December 2023), given the incremental evidence generation and clinical setting changes. Search terms are provided as online supplemental file 1.

Eligibility criteria for considering studies for the reviews

As our aim was to gain an overview of the clinical effectiveness evidence for the use of RAS, we included published systematic reviews (SRs) of robotic surgery in any surgical field compared with laparoscopic or open surgery and included any outcome measure. We excluded any systematic review which looked at aspects of RAS other than the clinical effectiveness of RAS. We excluded reviews which were unable to report on outcomes of RAS separately from other minimally invasive procedures. We excluded conference abstracts and review protocols as they generally provide insufficient information.[14] Reviews not in English were excluded, while this could be a limitation, and there is evidence that such language exclusion does not cause bias.[15]

Study selection

The first author (T-JL) screened the titles and abstracts of the identified articles. Duplicate publications were managed and removed using the Endnote software.[16] A random sample of 10% with an Excel algorithm of papers was screened by two authors (KAB and JB) to confirm the exclusion criteria and ensure a systematic approach to inclusion/exclusion.[17 18] Where the first author was uncertain about whether to include a paper, this was reviewed by KAB and JB and any disagreements were resolved by discussion. We introduced a two-stage study selection as we wanted to identify the volume of current evidence across specialties and examine the strength of evidence in areas where RAS is still in equipoise. In stage one, we included all systematic reviews (SRs) of the clinical effectiveness of RAS versus conventional surgeries. We then categorised identified articles by specialty in order to obtain the landscape of clinical uses of RAS. In stage two, we limited our review to a number of intracavity procedures in four specialties (colorectal, gynaecology, upper GI and HPB). We chose four specialties where there is a building evidence base but RAS is not dominant.[19] The selection process is reported in the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) flowchart.[20]

Data extraction and synthesis of results

The extracted data from the systematic reviews included author, year of publication, setting, study design, sources, number of included studies, participants (ie, diagnosis for procedures), intervention (types of interventions compared, numbers assigned in each group), a range of clinical outcomes, quality rating given to the papers and conclusions of the SRs. The high level of heterogeneity in the patient population and procedure precluded meta-analysis. We conducted a descriptive analysis and tabulated the results by outcome for six procedures (colorectal oncological resection, hysterectomy, liver resection, pancreatectomy, pancreaticoduodenectomy and gastrectomy) in the four specialties of interest.

For all SRs, we summarised their clinical outcomes by using broad descriptors (positive, neutral or negative) for each procedure. The volume of defined descriptors from the SRs by clinical outcomes was counted in six procedures. We used a traffic light system to present the descriptors; green represents 'positive effect'; red represents 'negative effect', indicating a statistically significant finding in favour of the conventional surgical technique and yellow is 'neutral', which means that no statistically significant difference was found. It should be noted that these statistically significant findings may not indicate clinical significance. This bespoke mapping method allowed us to present a clear picture of the strength of the identified evidence. We did not synthesise evidence; therefore, no sensitivity analyses were conducted to assess the robustness of the synthesised results. However, we provided information on the heterogeneity of each meta-analysis in the supplementary file, if available.

Assessment of methodological quality and overlap management

We evaluated the quality and risk of bias of the included reviews using A MeaSurement Tool to Assess systematic Reviews (AMSTAR)-2 which is designed to evaluate the systematic reviews including both randomised and non-randomised study designs.[21] The assessment for the reviews was not taken as an inclusion criterion but was presented alongside the descriptive analysis of the evidence to allow the reader to form a judgement about the quality of the evidence available. Details are provided as online supplemental file 2.

In reviewing systematic reviews, there is a risk that underlying studies may be included in more than one of the identified systematic reviews. This overlap may give excessive weight to certain studies and bias the results. We used the citation matrix, the corrected covered area method (CCA) to manage this issue.[22 23] Details for CCA are provided as online supplemental file 3.

RESULTS

Study selection

Through the systematic search, 3363 potentially relevant articles were obtained initially, 1208 duplicates were removed and 2155 proceeded to screening. After assessing for exclusion, there were 628 articles remaining and then categorised by specialty. For the studies with procedures out of interest (n=451) and no accessible full text (n=12), they were excluded. A total of 165 systematic reviews were included for this overview, and the study selection process is summarised in figure 1 with a PRISMA flowchart.[20]

Volume of reviews by specialty

Our review included SRs published within 5 years from 2017–2023. Figure 2 presents the volume of reviews identified by specialty. The highest number of reviews was identified in urology (n=131), where RAS is well-established, followed by colorectal (n=89), HPB (n=77), gynaecology (n=59) and upper GI (n=50).

Evidence of clinical outcomes

We identified a wide range of outcomes across the included systematic reviews and categorised them as surgical, postoperative, oncological or long-term outcomes. These outcomes were summarised with descriptors and their numbers of sources were recorded across every procedure. The underlying data is presented in online supplemental file 4. Figure 3 shows a comparison of clinical outcomes for RAS compared with conventional laparoscopic approaches, across procedures with a colour spectrum where red represents a negative, yellow a neutral and green a positive result. Where the evidence is mixed positive, neutral and negative, this is indicated by brown. The gradient colour presents the strength of the evidence. Generally, RAS compared with conventional surgeries has an overall neutral in yellow and positive in green picture across all forms of outcome except operative time.

Operative time

Overall, operating times are equal or longer for RAS compared with laparoscopic surgery (LS) and open surgery; hence, the orange to red colour spectrum of evidence is presented in figure 3.

In colorectal oncological resection, 28 out of 33 included meta-analysis studies[24–51] and they all indicated that total operating time on average in the RAS groups was significantly longer than the LS groups. In contrast, in gynaecology, nine out of 12 studies reported insignificant operative time differences for hysterectomy compared with LS and six out of 9 studies compared with open surgery. Within HPB, the mean differences in operative time vary by procedures. In hepatectomy, 14 out of 18 reviews[52–65] reported that RAS had a significantly longer operative time compared with LS, while all included reviews reported RAS had a significantly longer operative time compared with open surgery. In pancreatectomy, two out of seven reviews[65 66] indicated that RAS had a significantly longer operative time compared with LS, two out of four reviews[65 67] compared with open surgery. In pancreaticoduodenectomy, one out of three studies[68] indicated RAS had a significantly longer operative time compared with the LS approach, and 10 out of 11 studies[67–76] compared with open surgery. In the field of upper GI, 17 out of 18 reviews[77–93] reported RAS for gastrectomy had a significantly longer operative time compared with LS, and four out of five also had a significantly longer operative time compared with open surgery.[94–97] However, there was one study that indicated robotic surgery had a significantly shorter operative time than open surgery.[98] This study took results from a network meta-analysis, a technique which compares approaches both directly and indirectly to derive evidence of relative clinical effectiveness. Only one RCT involving RAS was included in the network which may limit the validity of the conclusion.

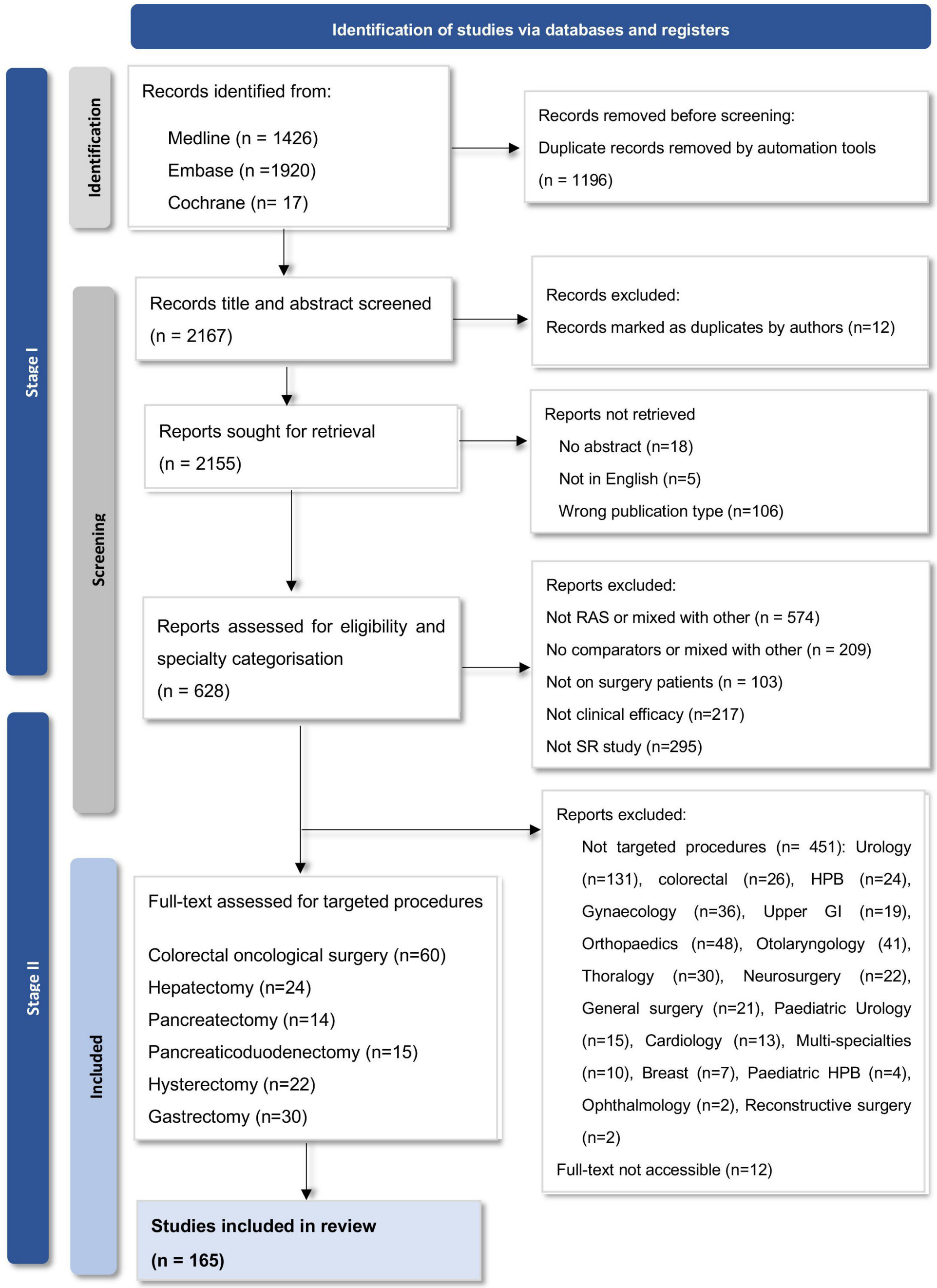

Figure 1 Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) flow diagram of systematic review selection process for the review of reviews. GI, gastrointestinal; HPB, hepatopancreaticobiliary; RAS, robot-assisted surgery.

Estimated blood loss

With the exception of hysterectomy and hepatectomy (both vs laparoscopic surgery), where the evidence for estimated blood loss was mixed, all other evidence for this outcome was in favour of RAS or neutral, as illustrated by the yellow to green spectrum in figure 3.

In the procedure of colorectal oncological resection, 12 out of 29 reviews[28 32 34 40 41 43 44 46 49 51 99 100] reported RAS had significantly less blood loss than LS, but the other 17 reviews did not find statistically significant mean differences. However, in hysterectomy, the evidence was inconsistent depending on the comparative procedures. Within the 14 reviews comparing RAS to LS which had data on blood loss, six studies indicated significantly less blood loss,[101–106] two studies reported significantly more blood loss[104 107] but six studies found no significant differences. When RAS was compared with open surgery, all eight reviews found positively that RAS had significantly less blood loss.[103 104 106–111] Within HPB, various effects could be seen depending on the procedure. For hepatectomy, among the articles comparing RAS to LS, mixed evidence was also identified. Five studies reported significantly less blood loss[55 112–115] while another four studies[52 53 59 64] indicated a contrasting result in favour of LS. But when comparing to open surgery,

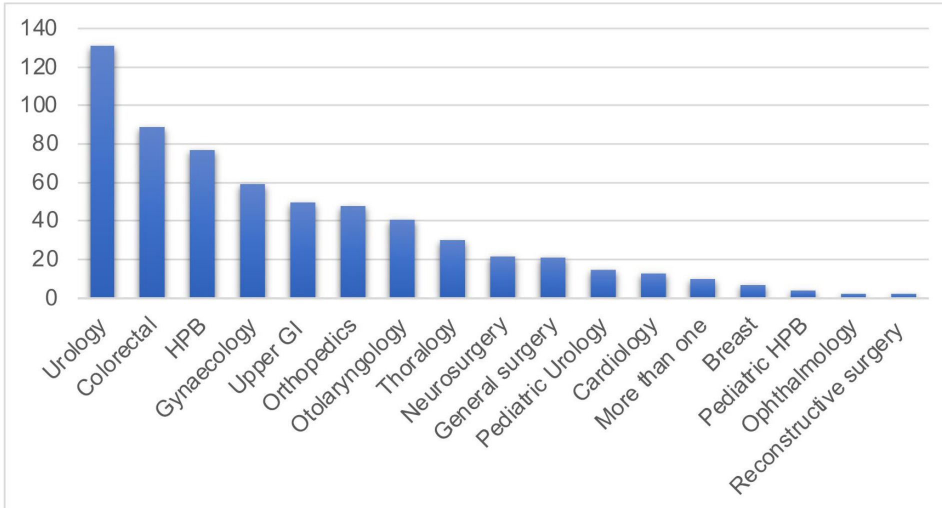

Figure 2 Number of systematic reviews identified by specialty. GI, gastrointestinal; HPB, hepatopancreaticobiliary.

five studies[59 113 116–118] indicated RAS was associated with significantly less blood loss while the other four studies found no significant differences. For pancreatectomy, three reviews reported RAS had significantly less blood loss than LS,[119–121] and three out of four reviews[67 119 122] reported RAS had significantly less blood loss than open surgery. For pancreaticoduodenectomy, two reviews identified RAS had significantly less blood loss than LS,[75 123] and all reviews indicated the result in favour of RAS compared with open surgery.[67–76 119 122 124] In respect of gastrectomy, 16 out of 20 included studies[78–89 93 95 125 126] showed that RAS had significantly less blood loss compared with LS, while all reviews reported RAS had significantly less blood loss than open surgery.[77–82 94–98]

Conversion rate

Identified evidence across all procedures showed either positive or neutral results in the conversion rate for RAS compared with LS, green to yellow is presented in figure 3.

Regarding colorectal oncological resection, 26 out of 35 included reviews[25–30 33–36 39 41–47 49–51 99 100 125–128] reported that RAS had significantly lower chances of conversion to open surgery compared with LS. In hysterectomy, three indicated RAS had significantly lower rates than LS,[101 103 106] and the other three reviews presented no significance. In respect of HPB, five of 20 included reviews indicated robotic hepatectomy had significantly lower conversion rates than LS.[54 58 112 115] For pancreatectomy

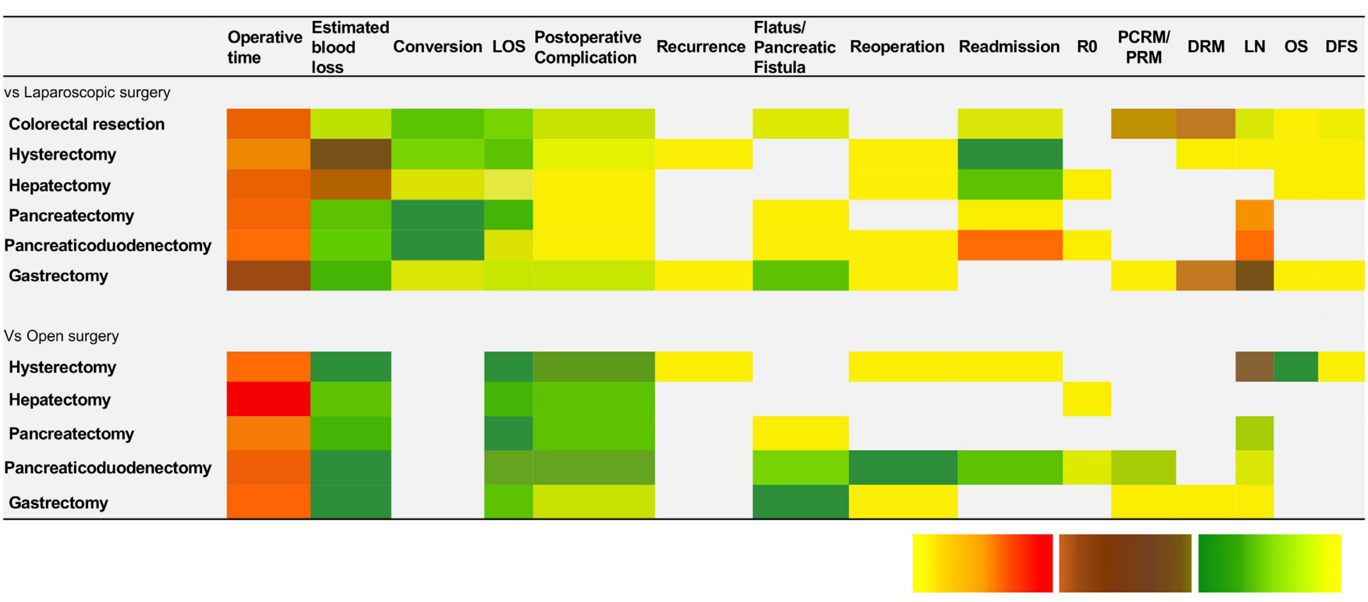

Figure 3 Evidence mapping across all targeted procedures. DFS, disease-free survival; DRM, distal resection margin; LOS, length of hospital stays; LN, lymph node; OS, overall survival; PCRM, positive circumferential resection margin; PRM, positive resection margin; R0, margin-negative resection.

and pancreaticoduodenectomy, all nine reviews suggested significantly lower conversion rates to open surgery than LS.[66 68 74 119 121 129–132] However, in gastrectomy, no significant conversion rate differences could be found from the included 13 out of 18 reviews.

Length of hospital stay

Identified evidence across all procedures showed that RAS compared with LS or open surgery had an equivalent or shorter duration of hospitalisation; hence, the green to yellow colour spectrum of evidence is presented in figure 3.

Among the included reviews of colorectal oncology surgery, 16 out of 37 articles[28 32 34–36 39 40 44–46 49 51 99 133–135] reported RAS had a significantly shorter duration of hospital stays than LS. For hysterectomy, 10 out of 13 studies[101–104 106–108 136–138] reported RAS had significantly shorter hospital stays than LS. Compared with open surgery, RAS also had a significantly shorter length of hospital stays.[103 106–111] In the field of HPB, only two studies for hepatectomy indicated RAS had a significantly shorter length of hospital stay than LS while the other 19 studies did not.[112 115] Eight out of nine[52 57 59 62 113 117 118 139] included studies showed significantly shorter duration than open surgery. Among the included systematic reviews for pancreatectomy and pancreaticoduodenectomy, six studies[65 119 129 130 140 141] reported RAS had a significantly shorter length of hospital stay than LS and almost all studies showed a significantly shorter length of hospital stay than open surgery.[65 67 68 70–74 76 119 122 124 142] As for gastrectomy, five out of 18 reviews[84 87 88 92 143] found RAS had a significantly shorter length of hospital stay than LS, and two out of four reviews[94 96] indicated RAS had significantly shorter stay compared with open approach.

Postoperative complications

For postoperative complications among all procedures, identified evidence for comparing RAS to LS tend to be neutral, while comparing RAS to open surgery tend to be positive as illustrated in the green to yellow colour spectrum in figure 3.

Among the identified reviews of colorectal oncology resection, seven out of 30 articles[34 36 43 46 50 134 144] showed that RAS in postoperative complication results were significant compared with LS. In hysterectomy, only one study found RAS had a significantly lower postoperative complication than LS,[137] while five out of eight studies were in favour of RAS than an open approach.[103 106 107 109 111] In respect of HPB including hepatectomy, pancreatectomy and pancreaticoduodenectomy, no significant difference in postoperative complication rate was found compared with LS. Some positive evidence when RAS was compared with open surgery: six out of 11 reviews for hepatectomy,[52 57 59 113 117 118] two out of five reviews for pancreatectomy[65 67] and six out of eight reviews for pancreaticoduodenectomy.[67 68 72 74 76 142] For gastrectomy, five out of 18[84 85 87 89 145] found RAS had significant differences in postoperative complication rates compared with LS, and only one compared with open surgery.[96]

Other clinical outcomes

There were other important outcomes identified among the selective procedures such as reoperation and readmission presented in figure 3. It is noted that there was various evidence identified in outcomes of readmission across all selective procedures when RAS compared with LS. Some procedures reported on postoperative mortality.[78 79 81 98 146–148]

Procedure-specific postoperative outcomes were also reported. For example, colorectal resection and gastrectomy had data on outcomes of first flatus,[32 35 39 50 81 84 85 89–92 98] pancreatectomy and pancreaticoduodenectomy on outcomes of pancreatic fistula[74 76 149] and bile leak.[150] Colorectal resection had reported urinary outcomes and sexual function[151–156] and other outcomes such as ileus and anastomotic leak.[156–158] More details for other clinical outcomes of the included systematic reviews can be found in online supplemental file 5.

Oncological outcomes

Different oncological outcomes were reported including the number of lymph node yield and resection-related outcomes (distal resection margin, positive circumferential resection margin, positive resection margin and margin-negative resection). Mix evidence in oncological outcomes was found across all procedures, especially when RAS compared with LS or open surgery, with a brown colour in the spectrum presented in figure 3. For example, lymph node yield in hysterectomy, RAS compared with open surgery had one study with a significant negative outcome,[103] three with positive outcomes[107 136 137] and four with neutral. One study also reported para-aortic lymph nodes.[159] In gastrectomy, RAS compared with LS also found eight with significant negative outcomes,[78 79 81 84 86 88 93 125] two with positive[88 90] and seven with insignificant outcomes. In pancreatectomy and pancreaticoduodenectomy, RAS compared with LS had one out of [66]six and two out of four reviews[123 132] had negative significance. Other oncological outcome was used, for example, completeness of total mesorectum excision.[160] More details can be reviewed in online supplemental file 5.

Long–term outcomes

Some reviews comparing RAS to LS reported overall survival and disease-free survival outcomes. In most of the studies, identified evidence was neutral with the yellow colour spectrum presented in figure 3, except one study showing RAS compared with open surgery had significantly longer 3-year overall survival in hysterectomy.[109]

Quality of included reviews and overlap management

Figure 4 displays that the quality of the systematic reviews was generally judged low or critically low across all procedures, using the AMSTAR-2 quality appraisal tool guidance.[21] Our assessment identified the critical flaw domain

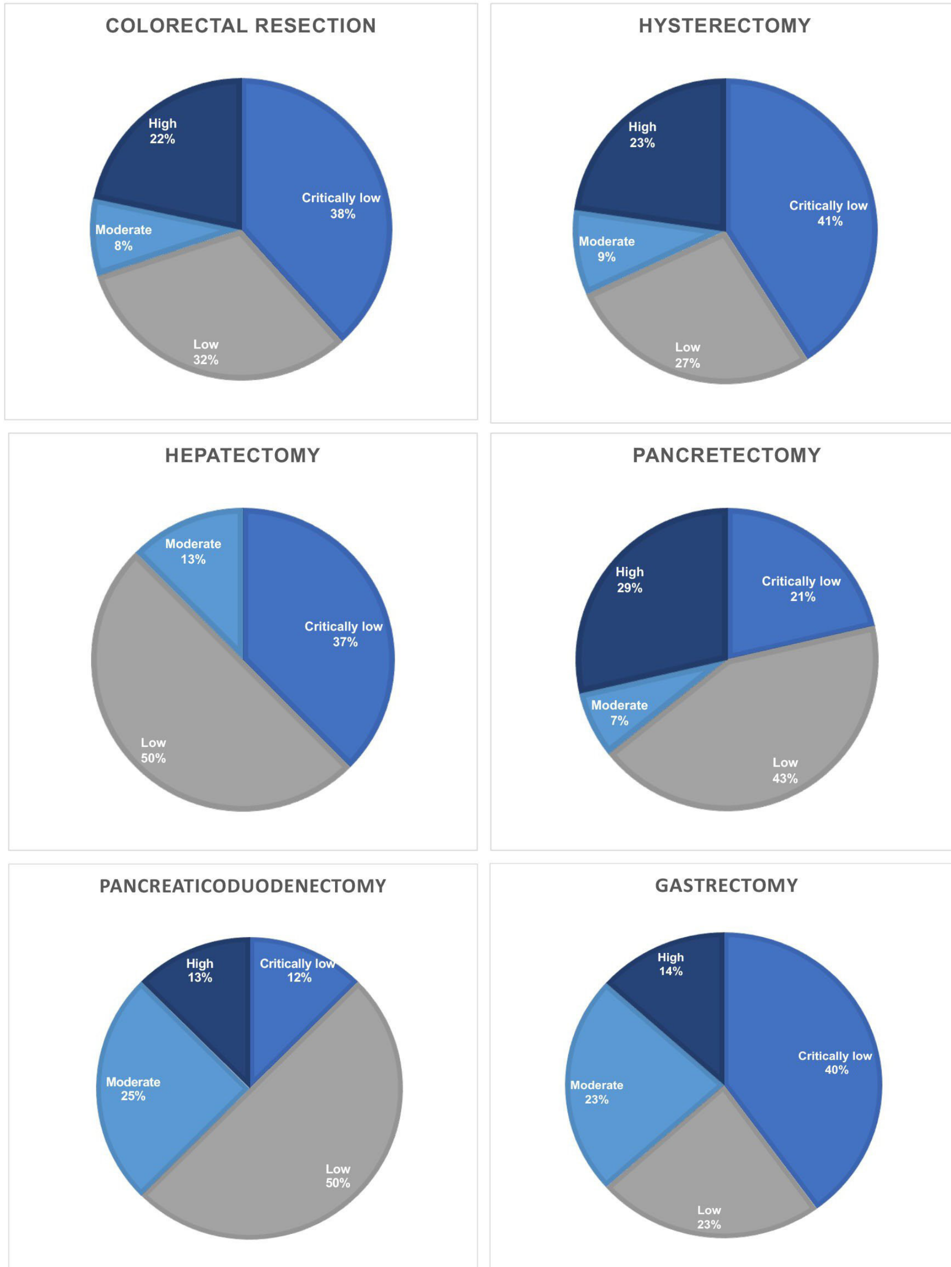

Figure 4 Quality assessment of systematic reviews in procedures of interest.

that the source of their primary studies does not impact quality, but poor management for risk of bias and publication bias does.

Regarding overlap management, the CCA value for colorectal oncological surgery is 6.4%, which is considered a moderate overlap. For hysterectomy is 3.3% which is considered just slight overlaps. For hepatectomy, pancreatectomy and pancreaticoduodenectomy, their CCA values are 13.62%, 17.6% and 22.73%, respectively considered as high and very high overlap. For gastrectomy with a CCA value of 8.42%, it is moderate. Given this level of overlap, we were aware of the risk of double-counting of individual studies within systematic reviews that would potentially impact on result and interpreted the evidence carefully.

DISCUSSION

The review offers an overview of the clinical outcomes of RAS and presents a summary of the clinical effectiveness evidence base to support the decision makers in optimising the utilisation of this technology.

We found RAS operative time was longer across all procedures. RAS had less estimated blood loss compared with open, but there was mixed evidence in hysterectomy and hepatectomy compared with LS. For conversion rate and length of stay, all the evidence indicated RAS had a lower conversion rate and shorter length of stay whether compared with LS or open. RAS had lower postoperative complications compared with open surgery, but we found no significant difference compared with LS. Across surgical procedures, we found the evidence is more positive when RAS is compared with an open approach.

A broad pattern of at least equivalent clinical outcomes of RAS was identified except for operative time. Longer operative time may be a temporary phenomenon because RAS is a relatively new technology which has a steep learning curve for individual surgeons and the whole support team. We recognise that the primary studies from the included systematic reviews covered RCTs could be quite dated, and observational studies and the different specialties which were the focus of our review are at different phases of adoption of RAS. Operative time with RAS may improve over time as the whole surgical and support team becomes more familiar with the technology.[161–164] In urology, where RAS is more established, evidence from large observational studies of robot-assisted laparoscopic prostatectomy shows a consistent decline in operative time and console time after overcoming the learning curve followed by a near-constant phase.[165] One study, also from urology, reported that surgeons with a higher caseload exhibited improved operative time compared with general caseload (266 min vs 240 min, $p<0.05$).[166]

A recent overview of reviews for RAS looked at multiple procedures (radical prostatectomy, hysterectomy, thoracic surgery (lobectomy and thymectomy), colorectal resection, nephrectomy, gastric and HPB procedures) and found, as we did, that RAS generally had a longer operative time.[10] It also found shorter operative time in hysterectomy for endometrial cancer and Roux-en-Y gastric bypass compared with LS. This may be because the review only looked at SRs including RCTs, whereas our review has included a broader range of SRs which incorporated evidence from observational studies. We found shorter operative time in gastrectomy compared with LS but this finding was from a single network meta-analysis including a single RCT.[98] Another overview of reviews which focused on a single procedure, total mesorectal excision for rectal cancer, also found that RAS had a significantly longer operative time than LS and open surgery.[167] Another two overview reviews for gastric cancer indicated that patients treated with RAS had significantly less estimated blood loss and shorter time to resumption of oral intake but prolonged operating time than patients undergoing LS.[168 169] In our overview, we also found RAS had significantly less estimated blood loss and a shorter time to resumption of oral intake than LS and open surgery in gastrectomy.

This finding was consistent with another overview of SRs.[168] Findings of poor quality mainly relate to reviewers' failure to explicitly deal with the bias inherent in real-world evidence. However, real-world evidence is critical in the evaluation of surgical techniques as randomisation is often difficult or impossible and randomised trial participants and surgeons may not be representative of the full population.

Our review is the first to summarise the full body of evidence of clinical outcomes and then further examine a number of specialties where there is still equipoise. This review is particularly relevant at the present time due to significant RAS expansion across non-urological specialties. We developed a novel evidence map with the concept of a colour spectrum to present the strength of evidence and its orientation. This study allows readers to capture both a broad perspective of the evidence landscape and in-depth information on the clinical effectiveness evidence. The results from this overview are likely to be generalisable to all countries as the SRs included studies from a broad range of settings. Although there would be a potential risk of bias when an SR included non-randomised studies, our AMSTAR-2 assessment has covered the item of risk of bias in each SR. The limitation of this overview review was that it adopted an existing search strategy supported by a two-stage selection process and focused on a selective number of procedures, given our research aim. It could have been more comprehensive.

Our findings have different implications for different categories of stakeholders. For patients, our results suggest that it is safe to move to RAS for all procedures examined, with outcomes equivalent or superior to traditional surgical methods. However, caution is advised for new procedures, as the first procedures chosen for RAS may have been the most suitable. For surgeons and other clinicians, although operative times are generally longer, they can be reassured about patient outcomes, and the presence of RAS may bring other benefits. These benefits include the attraction and retention of surgeons, the enhancement of their skill sets and the ability to work longer without fatigue or work longer before retirement. For healthcare providers, the use of RAS may bring the benefit of extending MIS to a larger proportion of patients. Where the uptake of LS has been low, perhaps due to technical difficulty, RAS may be more attractive to surgical teams.[3 170] Previous research has investigated the scalability of MIS, indicating that RAS rapidly substitutes both open and laparoscopic surgery over time, resulting in a higher proportion of MIS overall.[170 171]RAS was initially adopted for urological procedures. However, the limited operational days of surgical hardware may prompt hospitals to cross-specialty utilisation for optimal return on investment. A UK NHS study from 2000 to 2018 highlights RAS substituting incumbent technologies and expanding into diverse surgical specialties.[170] One study showed the proportion of hospitals and surgeons performing robotic surgery for selective procedures (including inguinal hernia repair colectomy, etc) increased from 3.1% in the first year to 13.1% in the fourth year after the implementation of surgical robots, leading to a trend towards less laparoscopic surgeries (−1.9%) being performed.[171] Another example where LS expansion could be considered to have stalled in the UK is laparoscopic colonic surgery. Rates of open colorectal cancer surgery remain between 30% and 40% and of those receiving laparoscopic resection, conversion to open surgery occurs in 10% in England and Wales.[172] Once the investment in RAS has been made, there may also be a higher level of institutional buy-in to extending its use, increasing the total proportion of patients being treated in a minimally invasive manner. The

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main concern may be around operative time. It might be a short-term phenomenon akin to a learning curve and might change over time as teams get used to new equipment. Alternatively, longer operative time could be a necessary disadvantage of a more complex set of equipment. Accordingly, other concerns for healthcare providers include the real costs of longer operative time, whether fewer procedures are being done and waiting lists are growing and whether higher prices charged for procedures compensate for the longer operative time.

In conclusion, the evidence suggests that RAS is a safe and effective alternative to LS and open surgery, with the potential to improve outcomes and enhance the capabilities of surgeons and healthcare providers and a particular opportunity to increase the proportion of minimally-invasive approaches. However, given the higher capital and running costs of the technology (ie, purchase of the robot, maintenance costs and the costs of disposables) and the longer operative times associated with its use, there is a need for careful consideration of its cost-effectiveness. Further research is needed to fully evaluate the value of these improvements in outcomes and to assess whether they outweigh the cost implications of the technology. Only through rigorous evaluation can we ensure that RAS is used in the most effective and sustainable manner possible after the initial investment, for the benefit of patients, surgeons and healthcare systems as a whole.

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